

STAR Upgrade Program and Future Physics

The 30th Winter Workshop on Nuclear Dynamics, April 6-12 2014

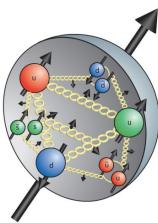
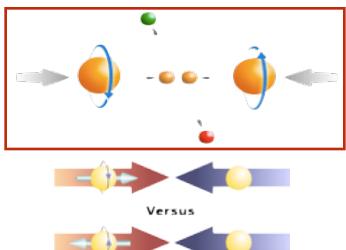
Yaping Wang
for the STAR Collaboration
(University of Illinois at Chicago)



Outline

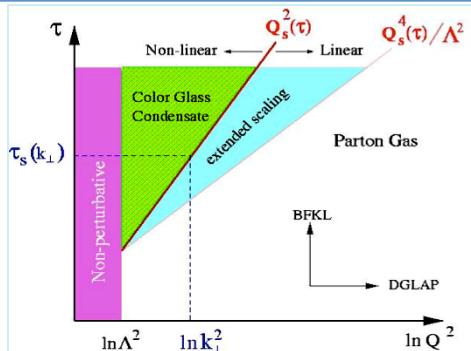
- Introduction
- Recent Upgrades and Physics Goals
 - Heavy Flavor Tracker (HFT)
 - Muon Telescope Detector (MTD)
- Future Upgrade Program and Physics
 - Inner TPC upgrade for BES II and eSTAR
 - Forward instrumentation upgrade for p+A and eSTAR
- Summary

Introduction -- STAR Physics Focus



Polarized $p+p$ program

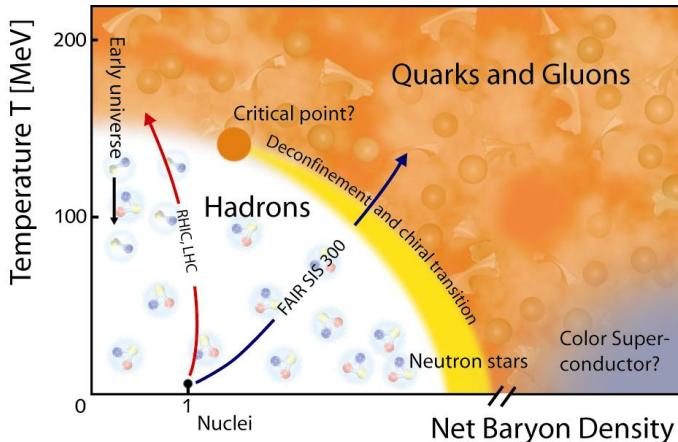
- Study ***proton intrinsic properties***
- ***QCD***



Forward program

- Study low-x properties, initial condition, search for ***CGC***
- Study elastic and inelastic processes in pp2pp

2025 -
eRHIC
(eSTAR)



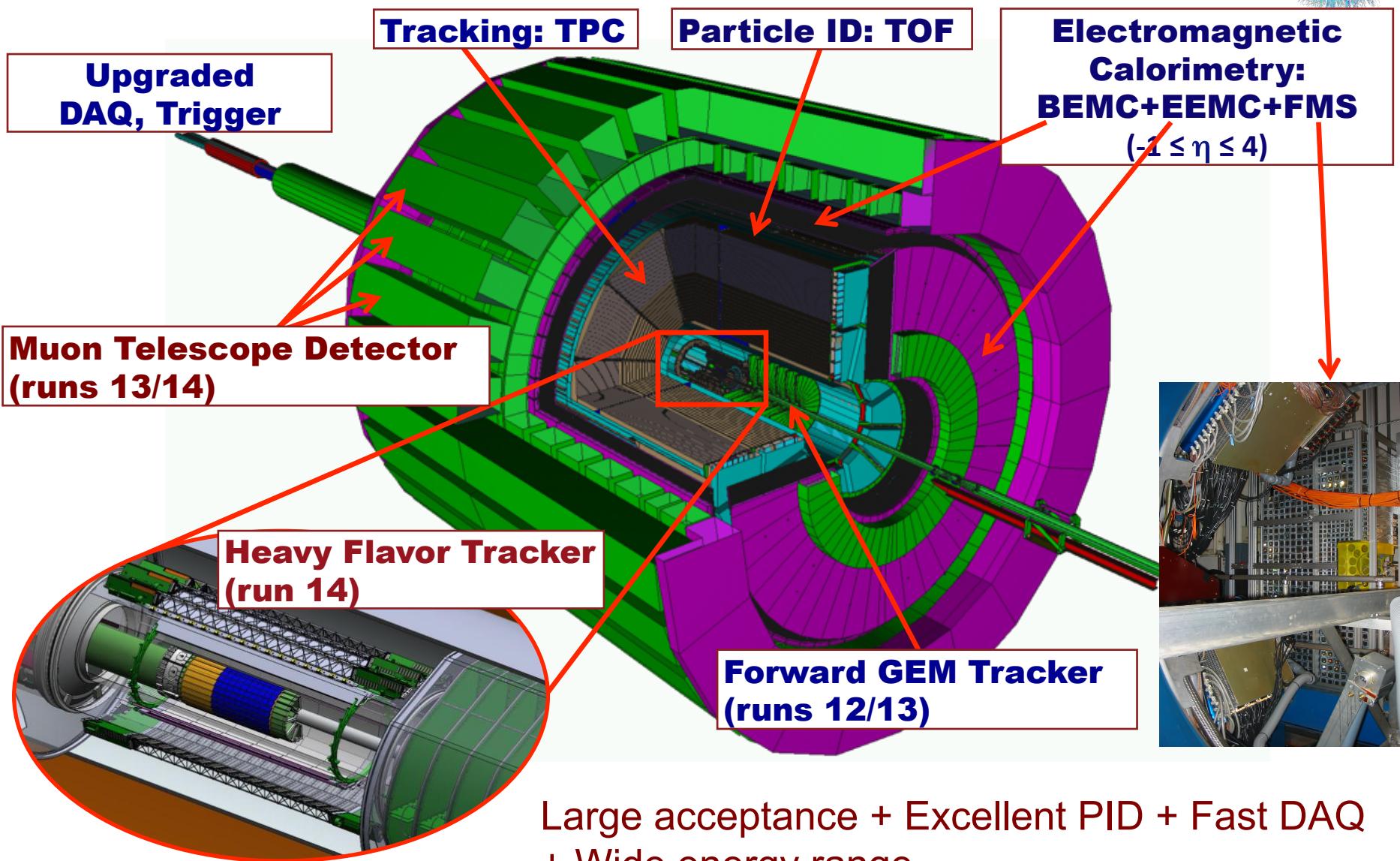
1) At 200 GeV at RHIC

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

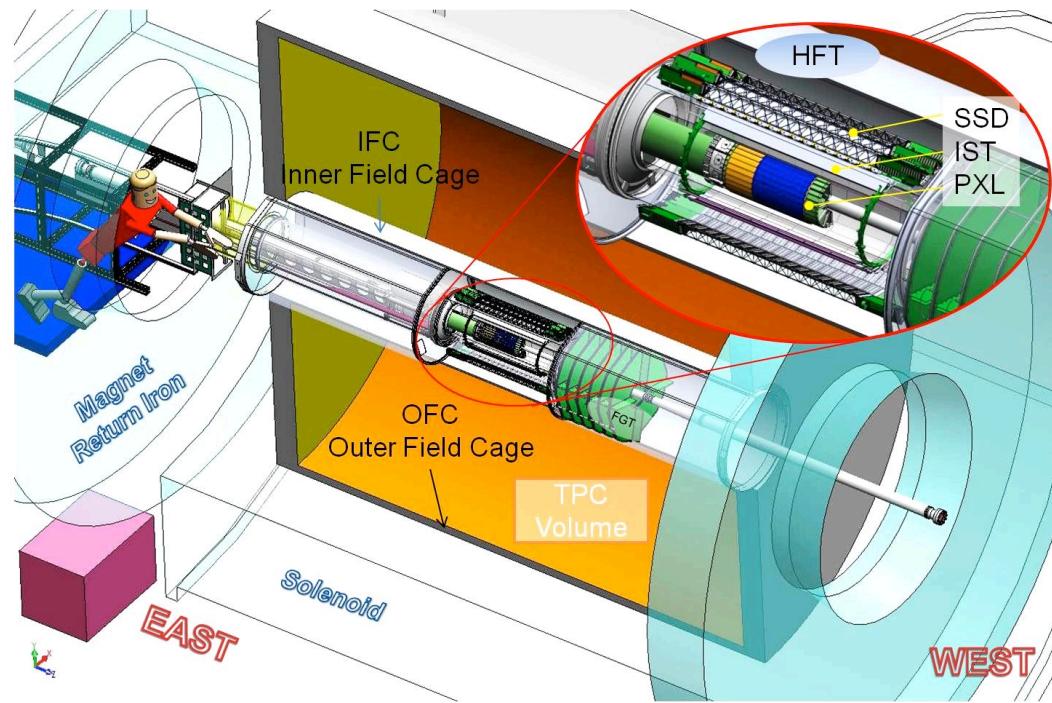
2) RHIC beam energy scan (BES)

- Search for the ***QCD critical point***
- Chiral symmetry restoration

Introduction -- The STAR Experiment (2014+)



Recent Upgrades – Heavy Flavor Tracker (HFT)



Detector	Radius (cm)	Hit Resolution R/ φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5% X_0
PIXEL	8	12/ 12	~0.4% X_0
	2.5	12 / 12	~0.4% X_0

PIXEL

- 2 layers of thin monolithic active pixel sensors, integration time $\sim 180 \mu\text{s}$
- $18.4 \times 18.4 \mu\text{m}$ pixel pitch
- Provide ultimate pointing resolution that allows for direct topological identification of charm.

SSD (Silicon Strip Detector)

- Existing single layer of double sided strip sensors (electronic upgrade)

Track inward from TPC with graded resolution:





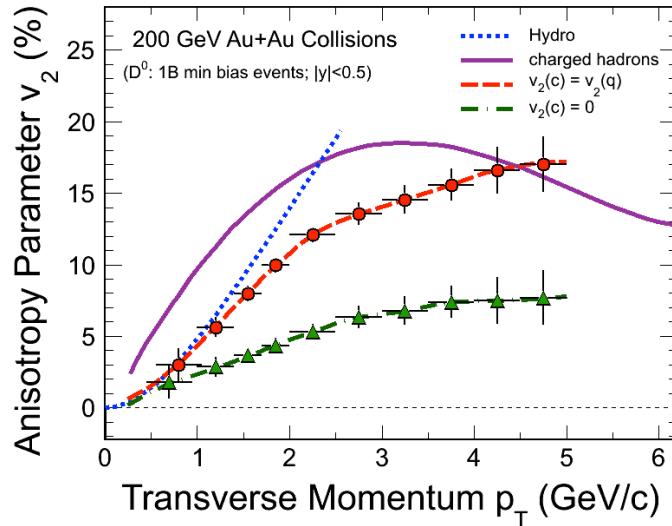
Recent Upgrades – HFT Physics Motivation

- Direct HF hadron measurements (p+p and Au+Au)
 - (1) Heavy-quark cross sections: $D^{0\pm*}$, D_s , Λ_c , B , ...
 - (2) Both spectra (R_{AA} , R_{CP}) and v_2 in a wide p_T region: 0.5 - 10 GeV/c
 - (3) Charm hadron correlation functions, heavy flavor jets
 - (4) Full spectrum of the heavy quark hadron decay electrons
- Physics motivation
 - (1) Measure heavy-quark hadron v_2 , heavy-quark collectivity, to study the medium properties e.g. light-quark thermalization
 - (2) Measure heavy-quark energy loss to study pQCD in hot/dense medium e.g. energy loss mechanism
 - (3) Analyze hadro-chemistry including heavy flavors

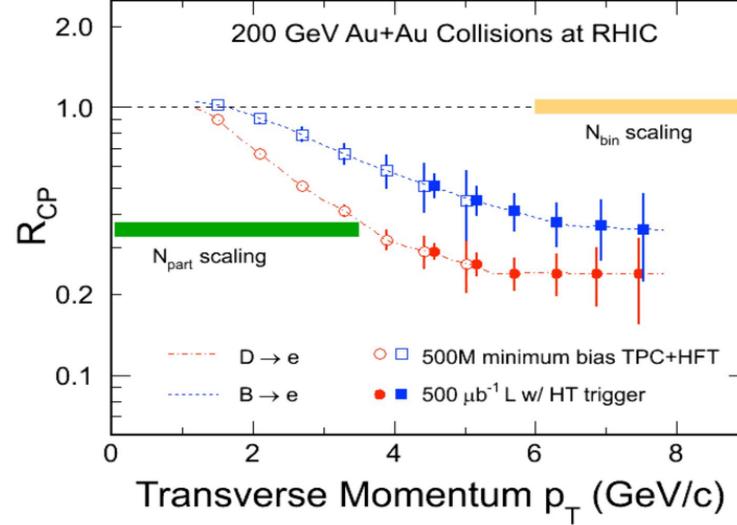
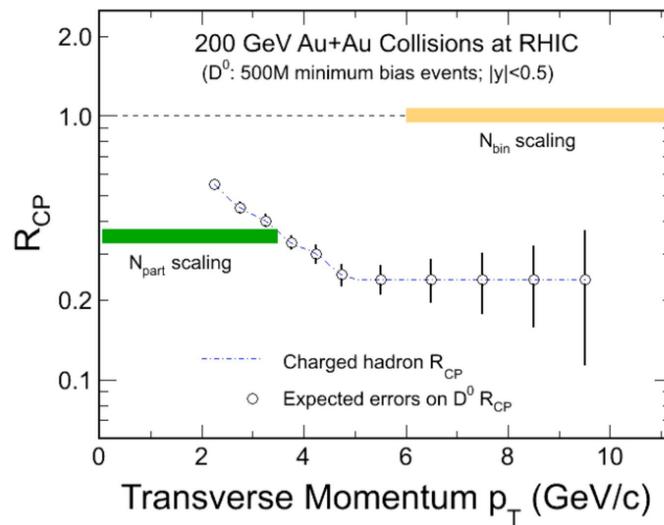
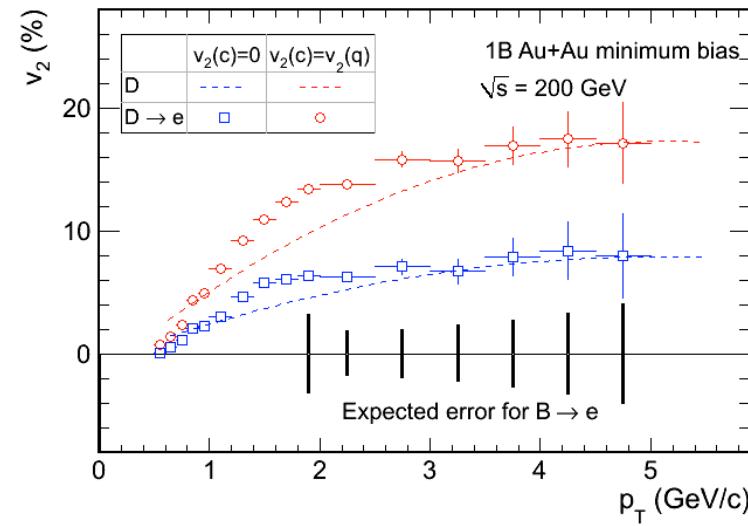
Recent Upgrades – HFT Physics Goals (Run 14, 15)



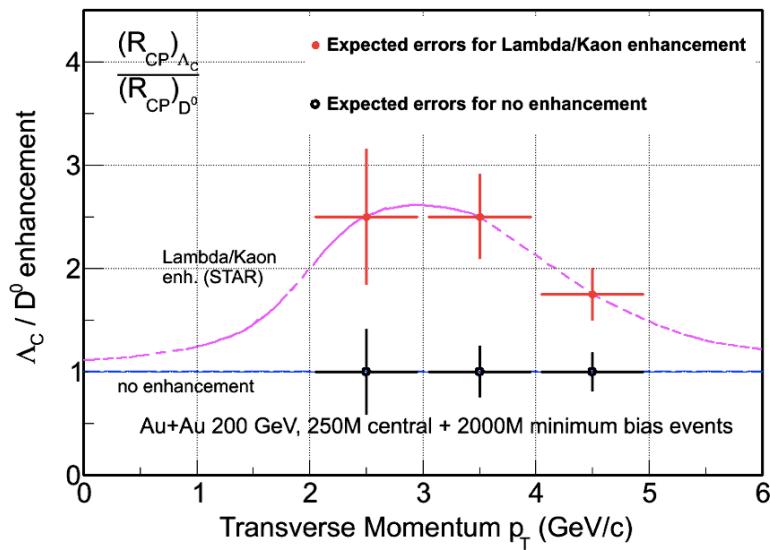
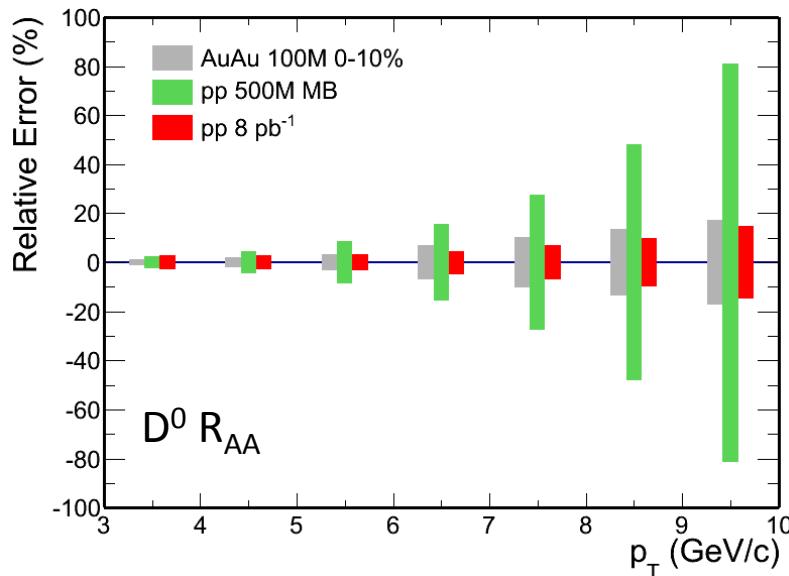
D0 mesons



HF decayed electrons



Recent Upgrades – HFT Physics Goals (Run 14+)

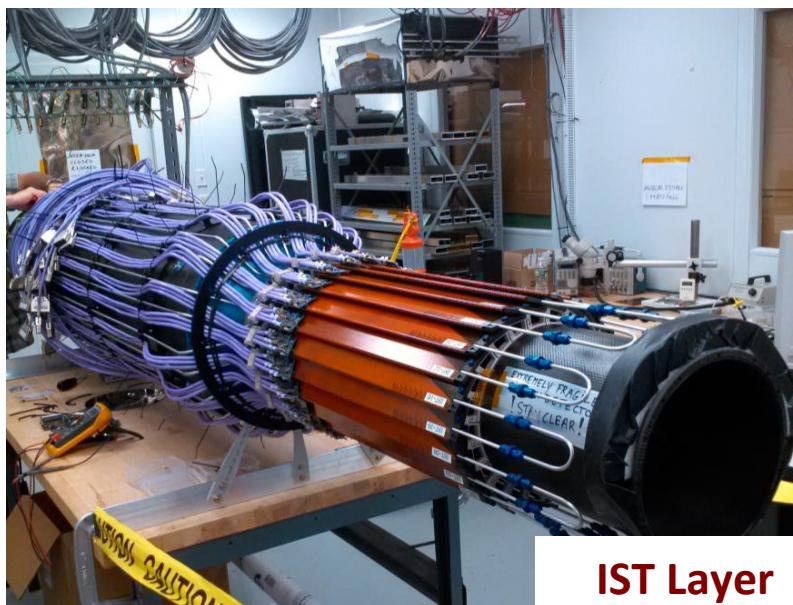
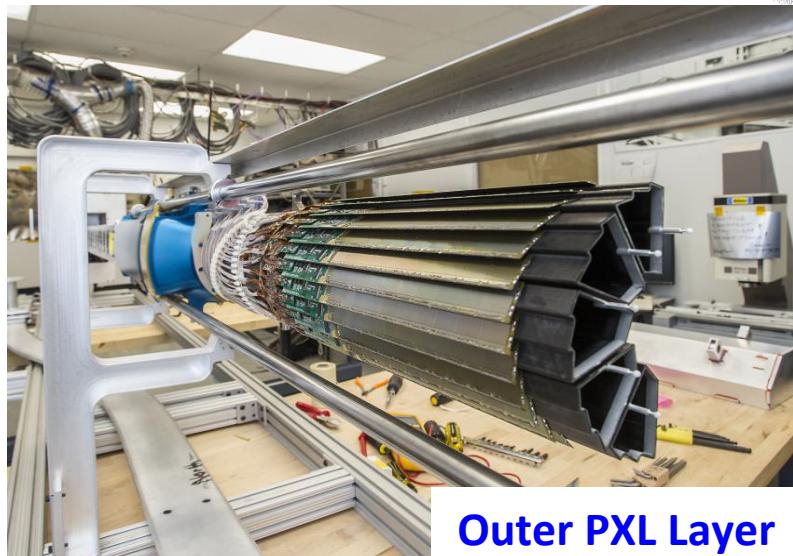
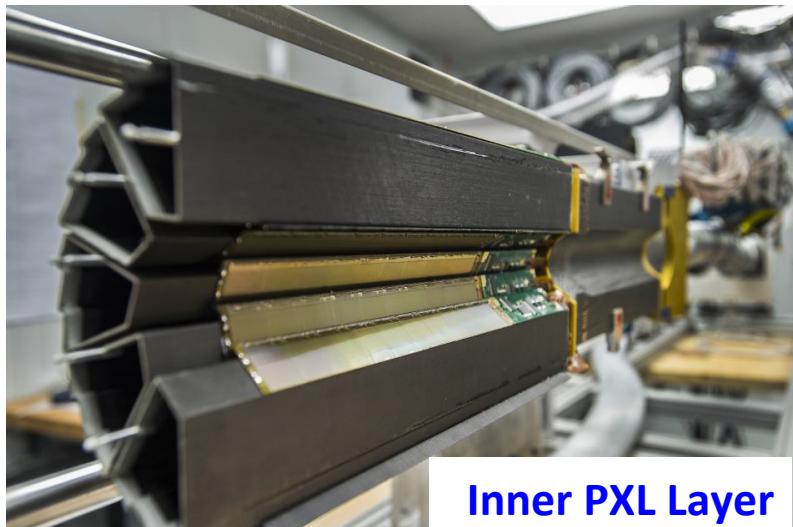


STAR multi-year physics program with the heavy flavor measurements requires high statistics data from both p+p and heavy ion collisions

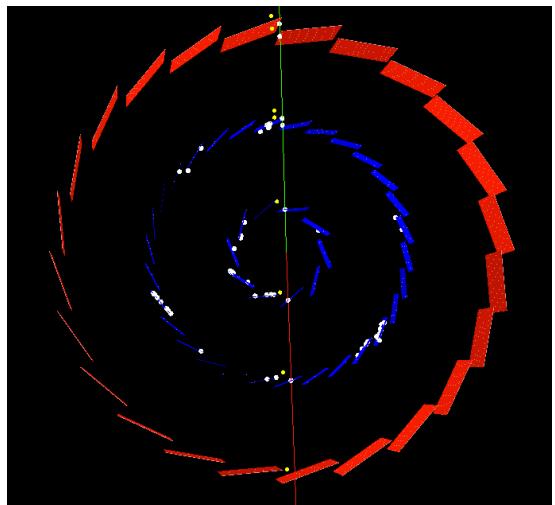
Λ_c : lowest charm baryon state, $c\tau \sim 60\mu\text{m}$

- First measurement of charm baryon in heavy ion collisions
- Hadro-chemistry with charm
- Meson vs. baryon effect with charm hadrons

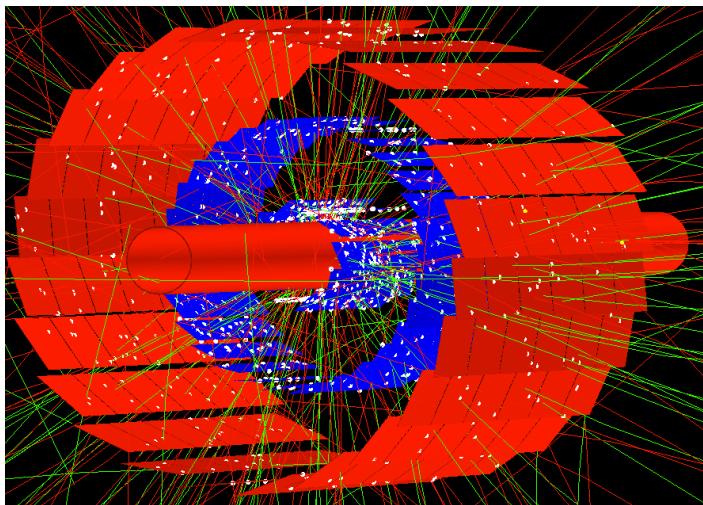
Recent Upgrades – HFT Installation in 2013/2014



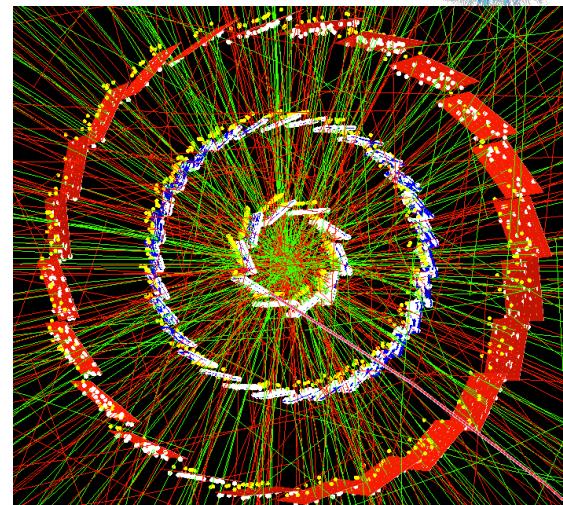
Recent Upgrades – HFT Commissioning in 2014



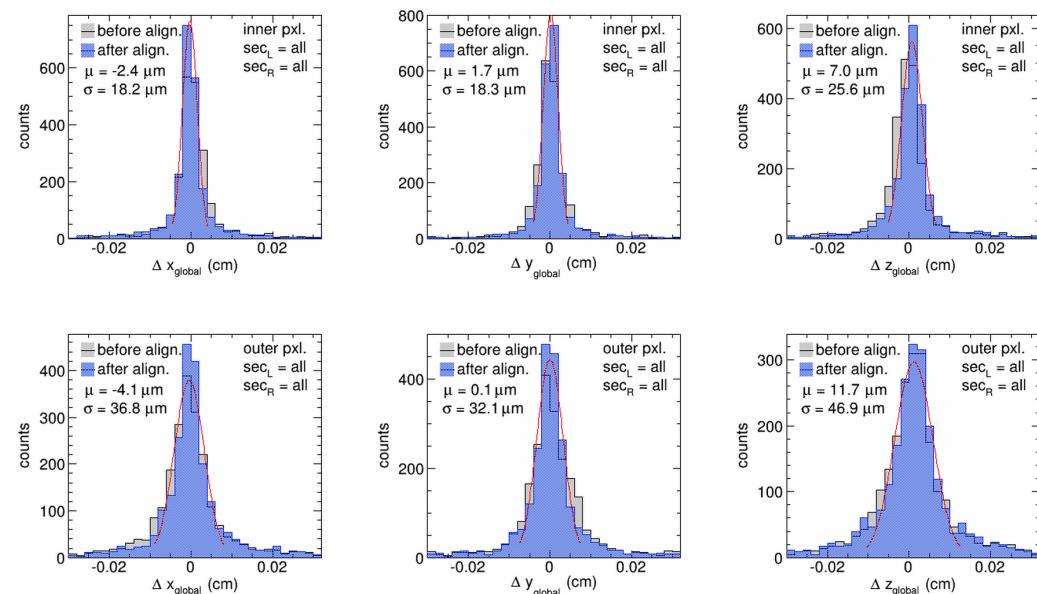
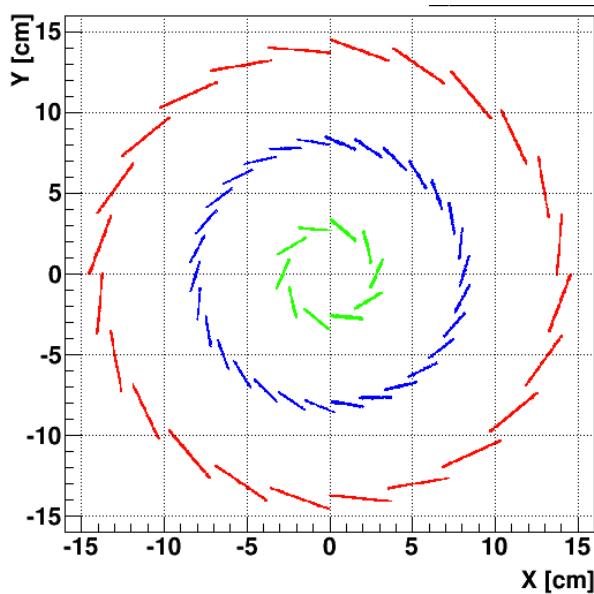
Cosmic run



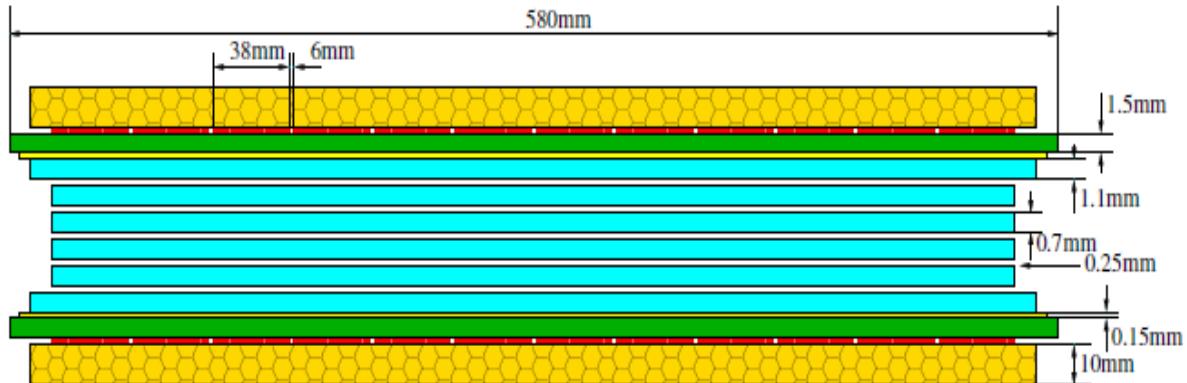
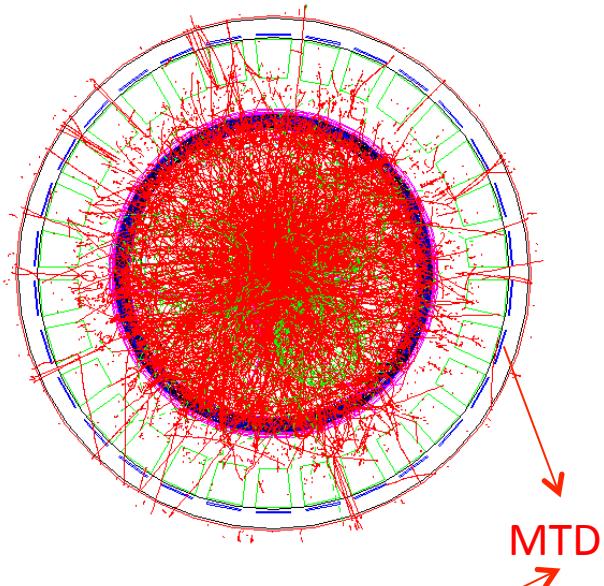
Au+Au @ 15 GeV



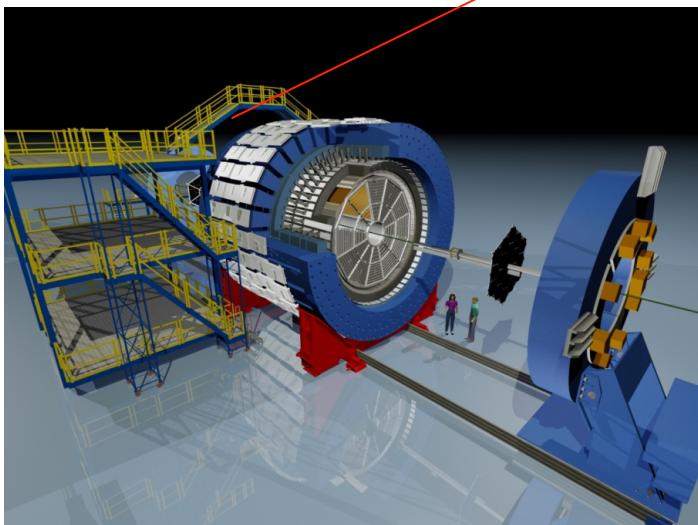
Au+Au @ 200 GeV



Recent Upgrades – Muon Telescope Detector (MTD)



Multi-gap Resistive Plate Chamber (MRPC):
gas detector, avalanche mode



A detector with long-MRPCs covers the whole iron bars and leave the gaps in-between uncovered. Acceptance: 45% at $|\eta|<0.5$

122 modules, 1464 readout strips, 2928 readout channels

Long-MRPC detector technology, electronics same as used in STAR-TOF



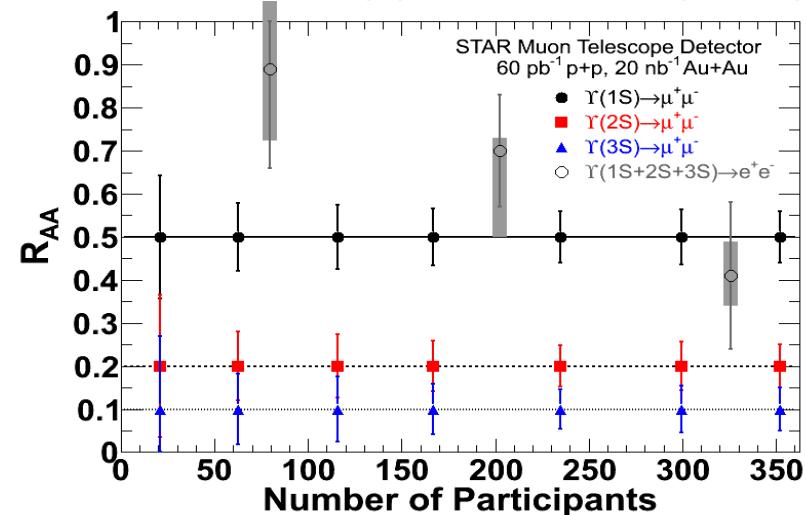
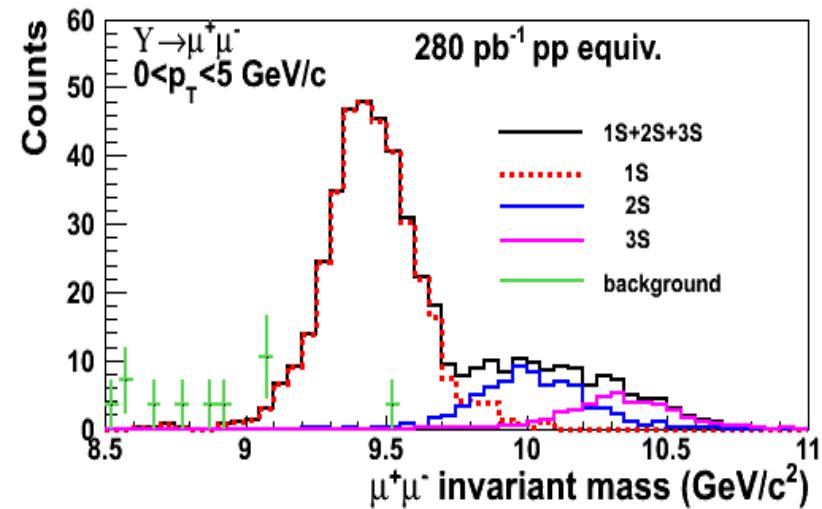
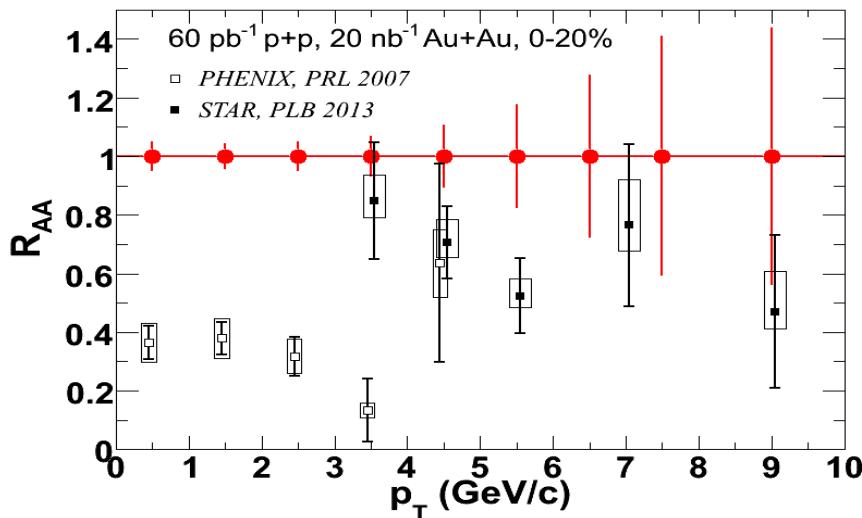
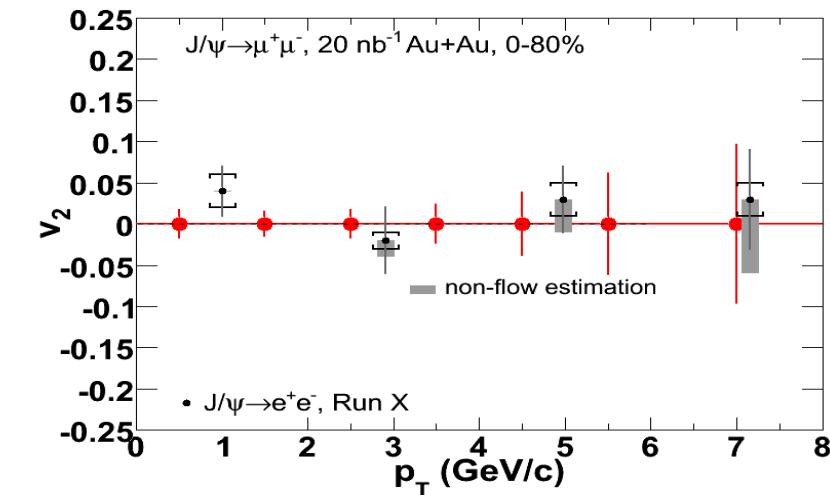
Recent Upgrades – MTD Physics Motivation

The large area of muon telescope detector (MTD) at mid-rapidity allows for the detection of

- Di-muon pairs from QGP thermal radiation, quarkonia, light vector mesons, resonances in QGP, and Drell-Yan production
- Single muon from the semi-leptonic decays of heavy flavor hadrons
- Advantages over electrons: no γ conversion, much less Dalitz decay contribution, less affected by radiative losses in the detector materials, trigger capability in Au+Au collisions
- Trigger capability for low to high p_T J/ψ in central Au+Au collisions and excellent mass resolution results in separation of different upsilon states
- $e-\mu$ correlation can distinguish heavy flavor production from initial lepton pair production

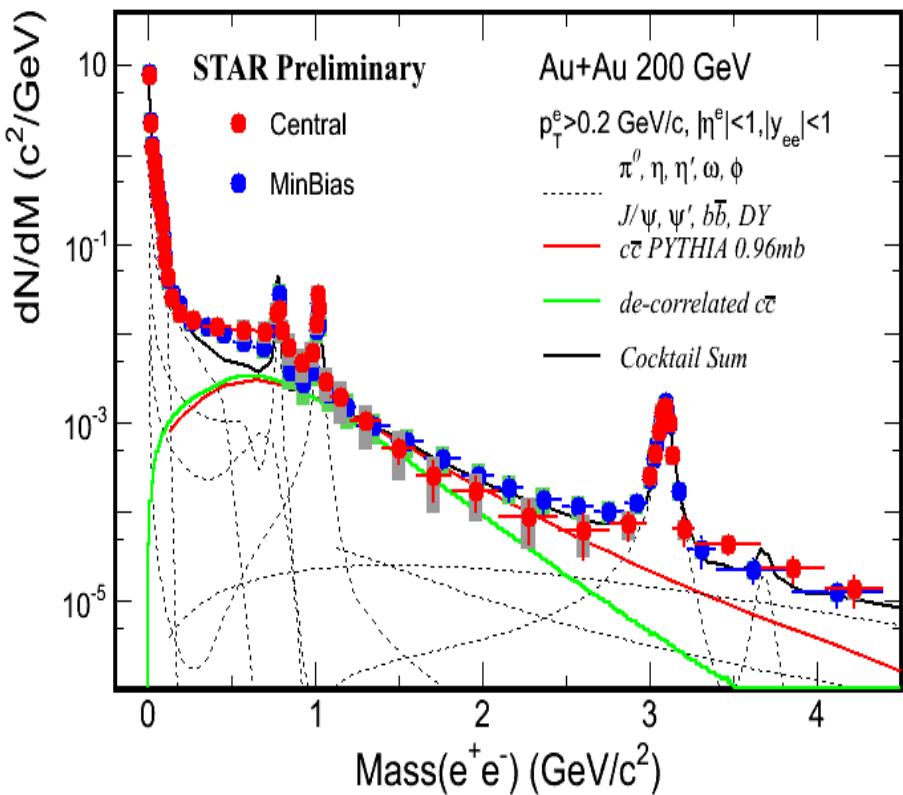
Recent Upgrades – Quarkonia from MTD

- Trigger capability for low to high p_T J/ ψ in central Au+Au collisions
- Excellent mass resolution, separate different upsilon states

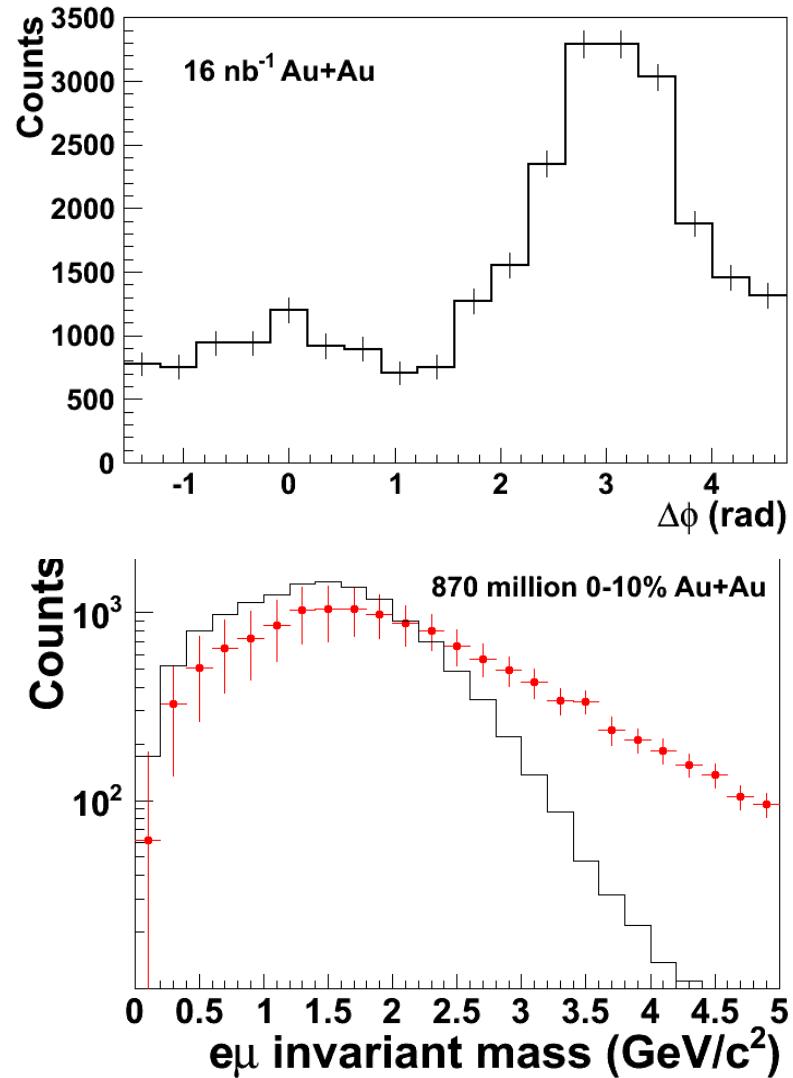


Recent Upgrades – e- μ correlation from MTD

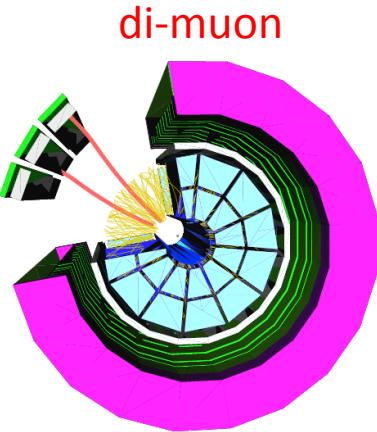
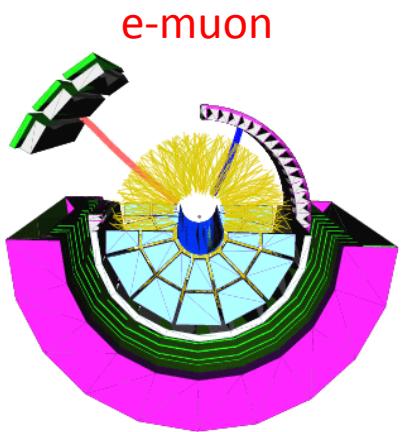
- e- μ correlation to distinguish heavy flavor production from initial lepton pair production



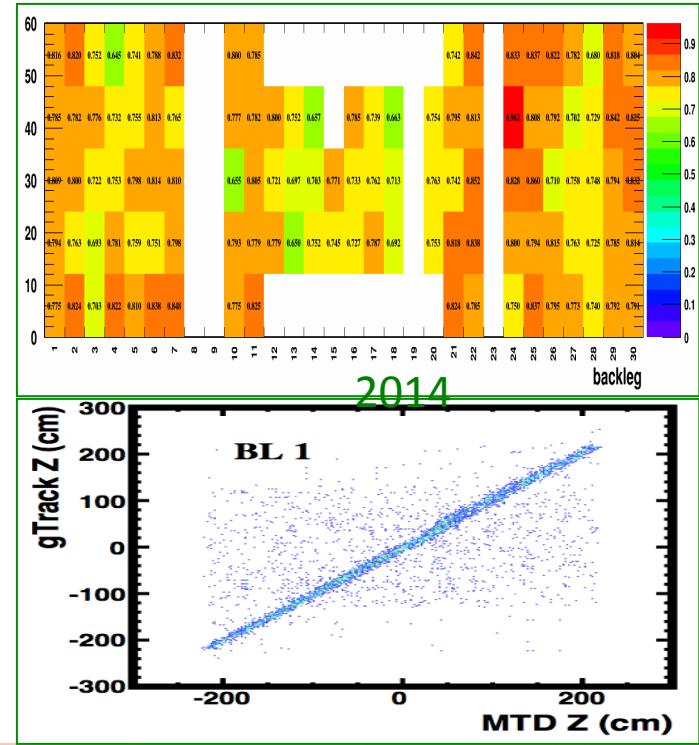
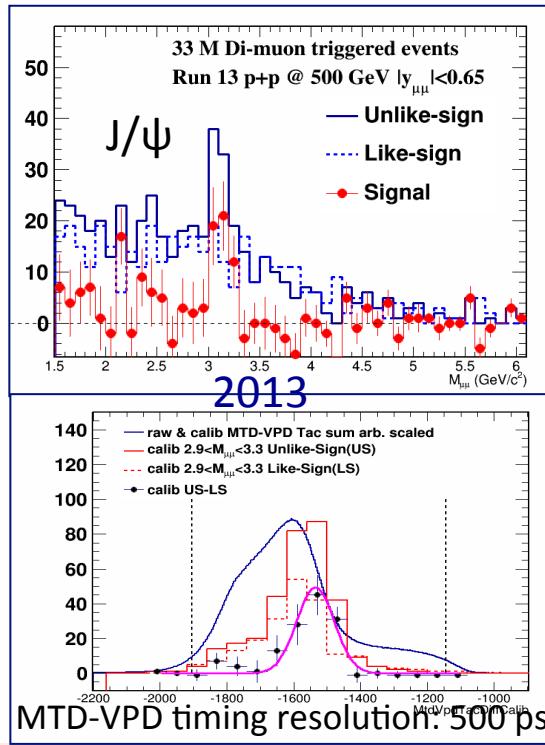
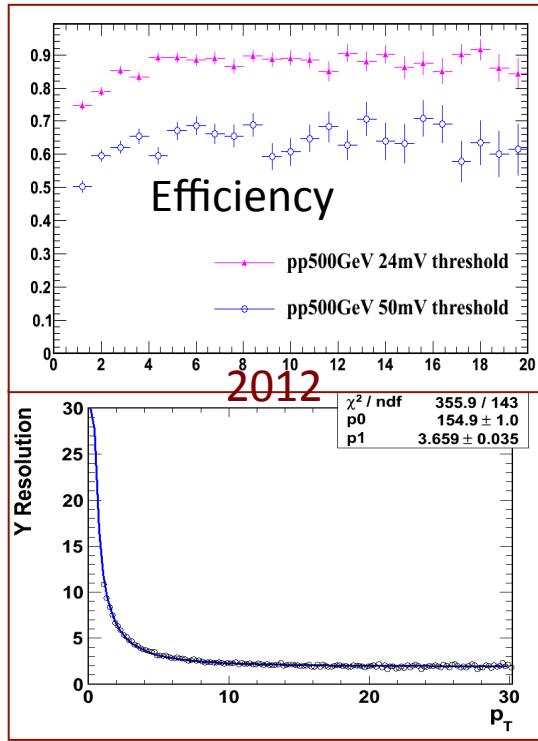
This measurements allow us to access the QGP thermal radiation contribution in the intermediate mass region (IMR).



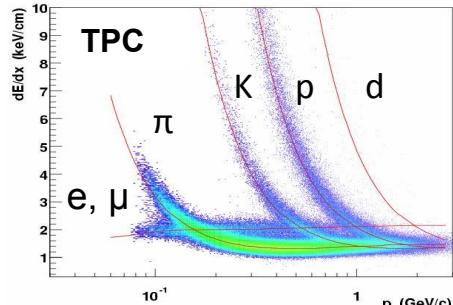
Recent Upgrades – MTD Performance



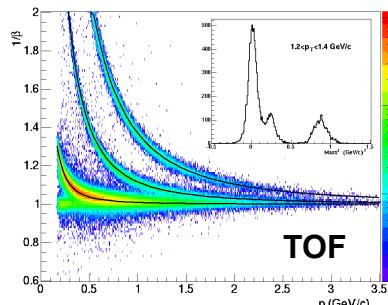
- Commissioned single muon, e-muon and di-muon triggers (event display for Cu+Au collisions)
- Optimized threshold setting, ~90% efficiency
- Intrinsic timing resolution: < 100 ps
- Spatial resolution: 1~2 cm
- Status (Ended in March, 2014):
2012 – 10%, 2013 – 63%, 2014 – 96-100%



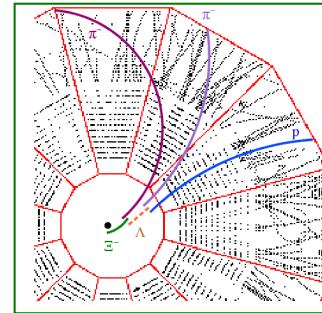
Recent Upgrades – Particle Identification in 2014+



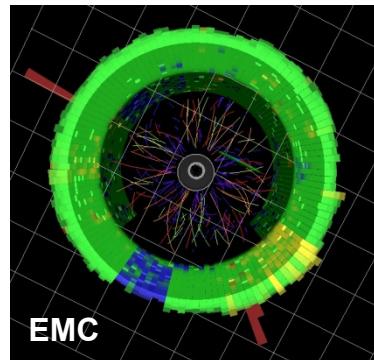
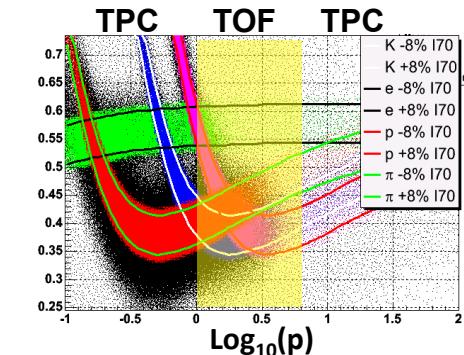
Charged hadrons



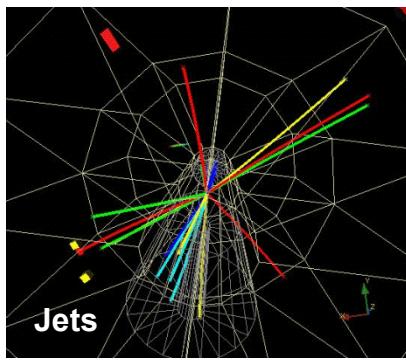
TOF



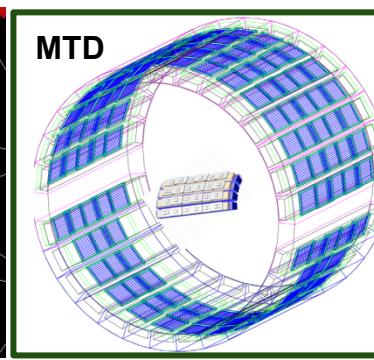
Hyperons & Hyper-nuclei



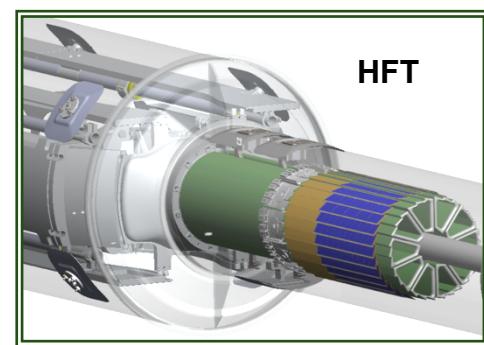
Neutral particles



Jets & Correlations



High p_T muons



Heavy-flavor hadrons

Multiple-fold correlations among the identified particles!
Nearly perfect coverage at mid-rapidity



Future Upgrade Program (2016+)

Detector Upgrades:

- TPC Inner Sector Upgrade
- Forward EM+Had Calorimeter System
- GEM or Si tracking in the very forward region
- PID Detector – Meson/Baryon separation

Physics Focuses:

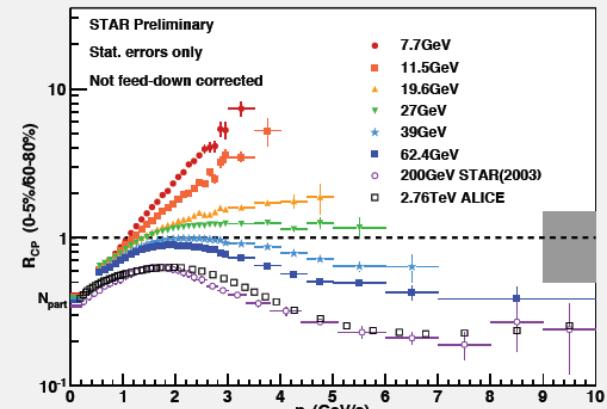
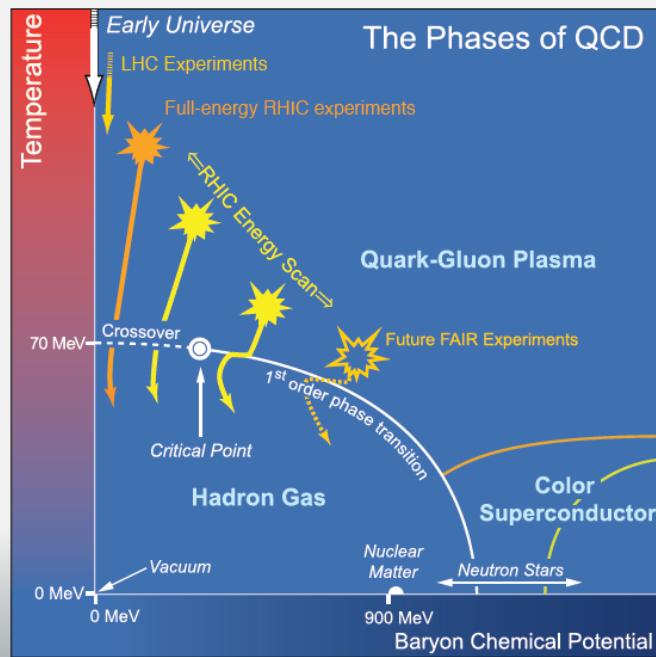
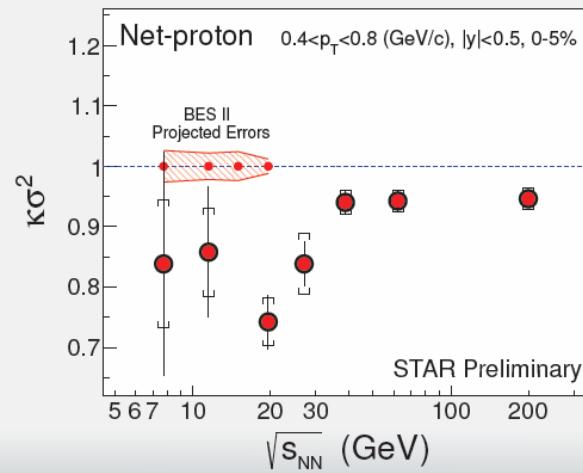
- Beam Energy Scan Phase II program (critical point)
- Forward photon/electron/jet(leading hadron)
- p+p -- transverse spin dynamics (transversity function and Collins FF, twist-3)
- pp/pA -- Drell-Yan, h-h, gamma-h correlations (initial conditions, gluon saturation)

Future Upgrade – Physics Goals of BES II Program

- QCD matter has a complex phase structure
- Heavy-ion collisions allow one to explore this structure by varying collision energy

Three Goals of BES program:

- Turn-off of QGP signatures
- Find critical point
- First order phase transition.



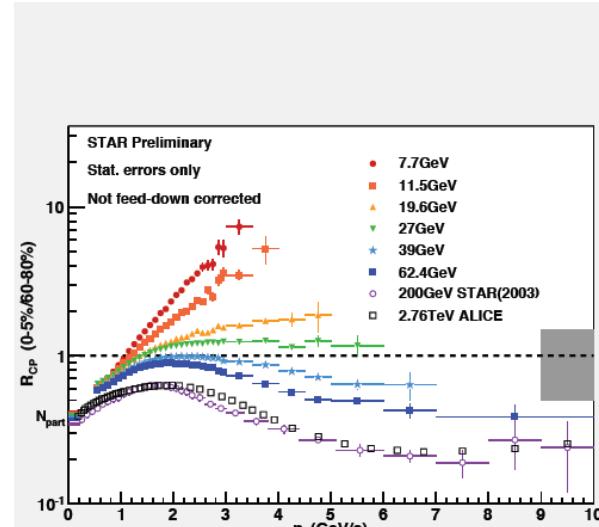
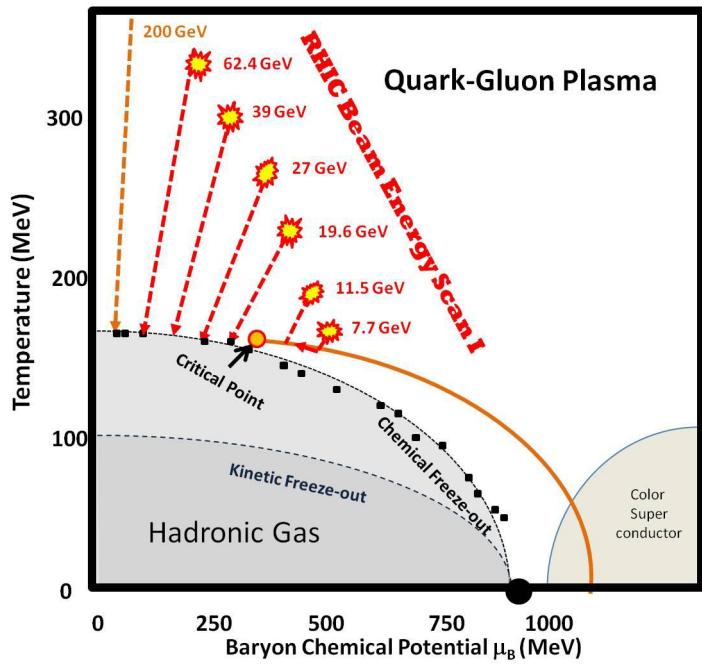
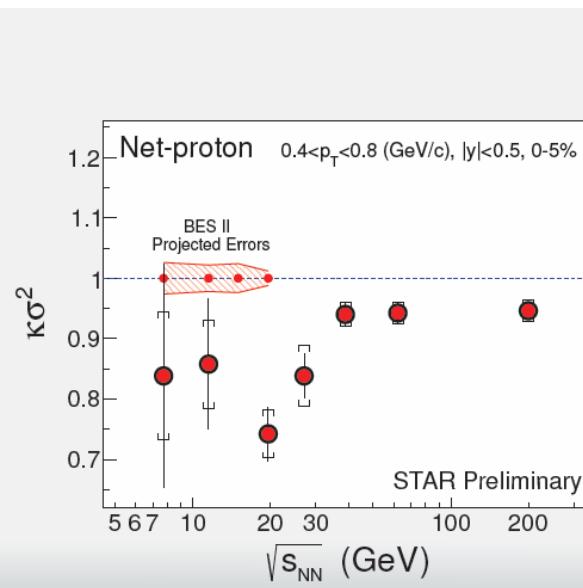
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- QCD matter has a complex phase structure
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Three Goals of BES program:

- Turn-off of QGP signatures
- Find critical point
- First order phase transition.

$\sqrt{s_{NN}}$ (GeV)	7.7	9.1	11.5	14.6	19.6
B (MeV)	420	370	315	250	205
BES II (Mevts)	100	160	230	300	400

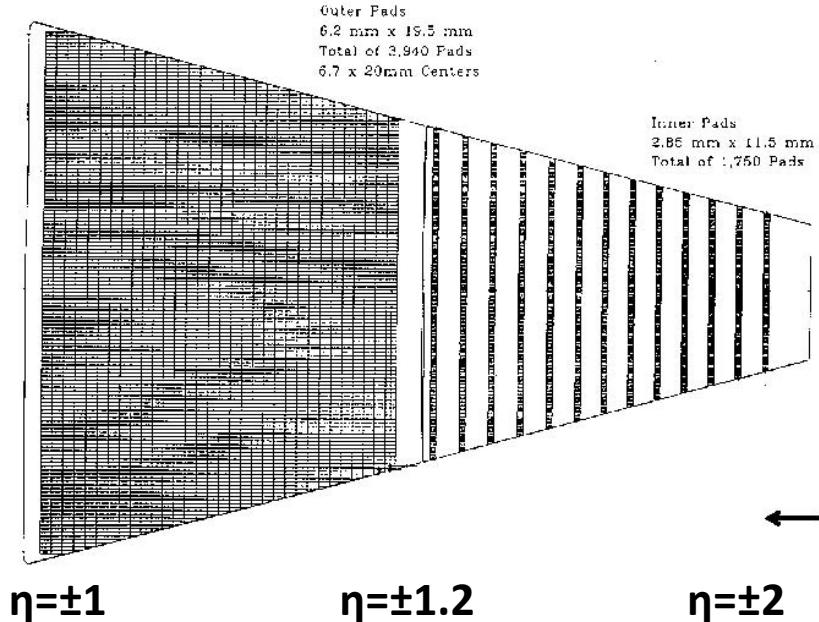


Future Upgrades – TPC Inner Sector Upgrade (iTPC)

- Current pad plane layout with 13 rows and gaps
 - ✧ only 13 maximum possible points
 - ✧ only reads ~20% of possible gas path length
- Inner sectors essentially not used in dE/dx
- Essentially limits effective acceptance to $|\eta| < 1$

iTPC Upgrade (2016+):

1. MWPC (SDU/SINAP)
2. Mechanics (LBL/BNL)
3. Electronics (BNL/ALICE)
4. Schedule 2017



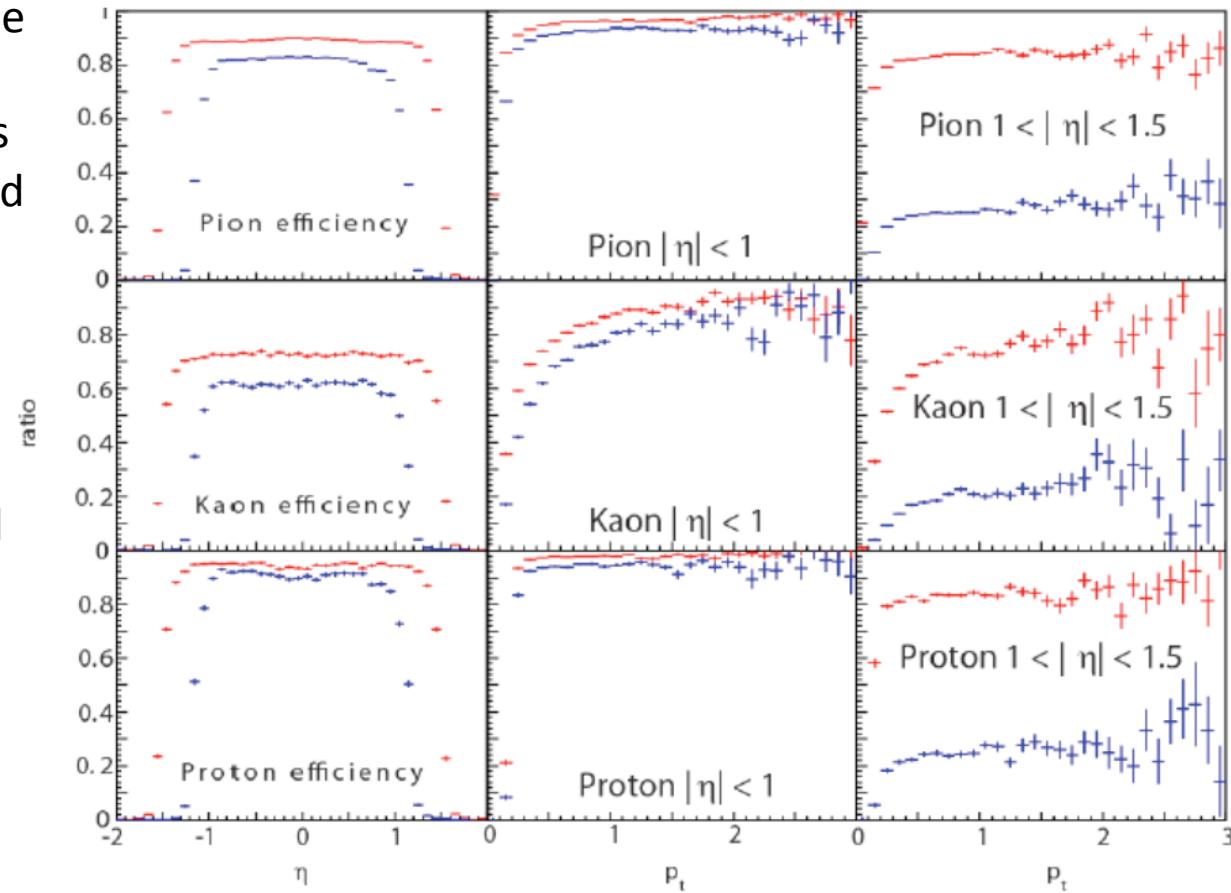
Future Upgrades – TPC Inner Sector Upgrade (iTPC)

Fill all inner sector with active pads -> better momentum resolution, better dE/dx resolution, higher track reconstruction efficiency and improved PID at $|\eta|=1.0-1.7$ region, broad impact on:

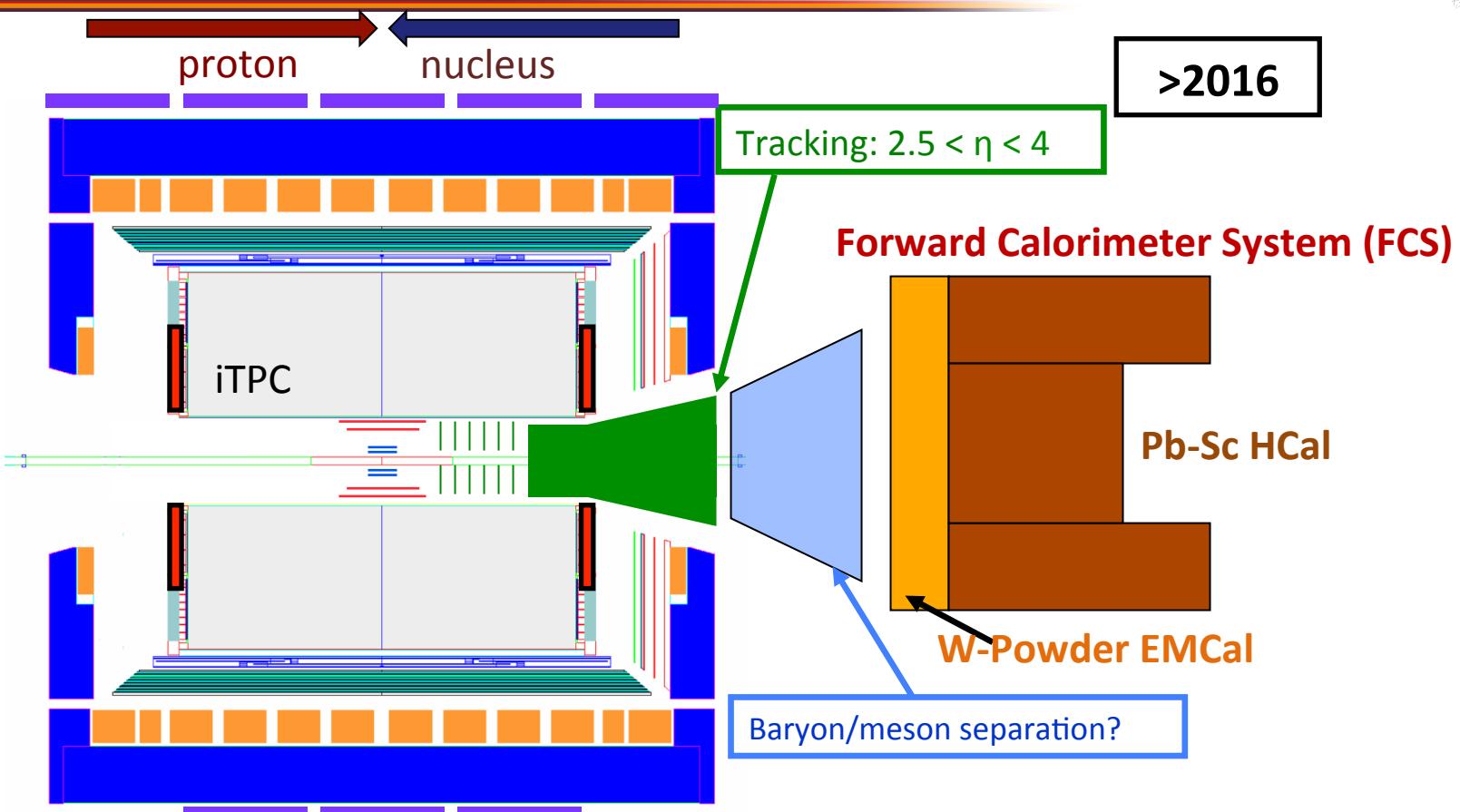
- transverse spin physics
- hyperon and exotic particle searches
- high pT identified particles
- essential for both BESII and eSTAR physics

Improved acceptance in p_T and η for reconstructed pion, kaon and protons.

Red points: iTPC
 Blue points: TPC

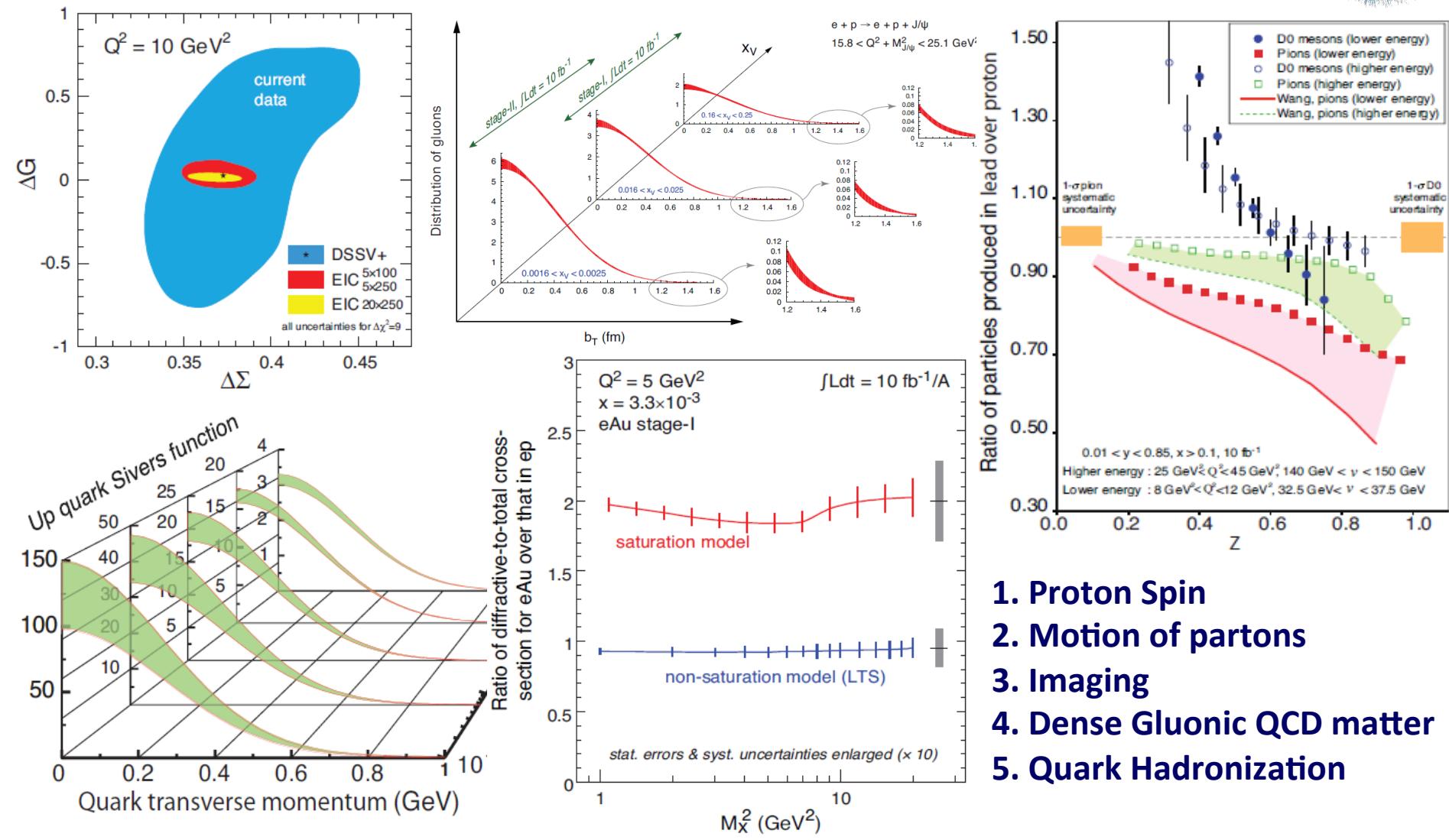


Future Upgrades – Forward Instrumentation Upgrade



- Forward instrumentation optimized for **p+A** and **transverse spin** physics
 - Charged-particle tracking
 - e/h and γ/π^0 discrimination
 - Possibly baryon/meson separation

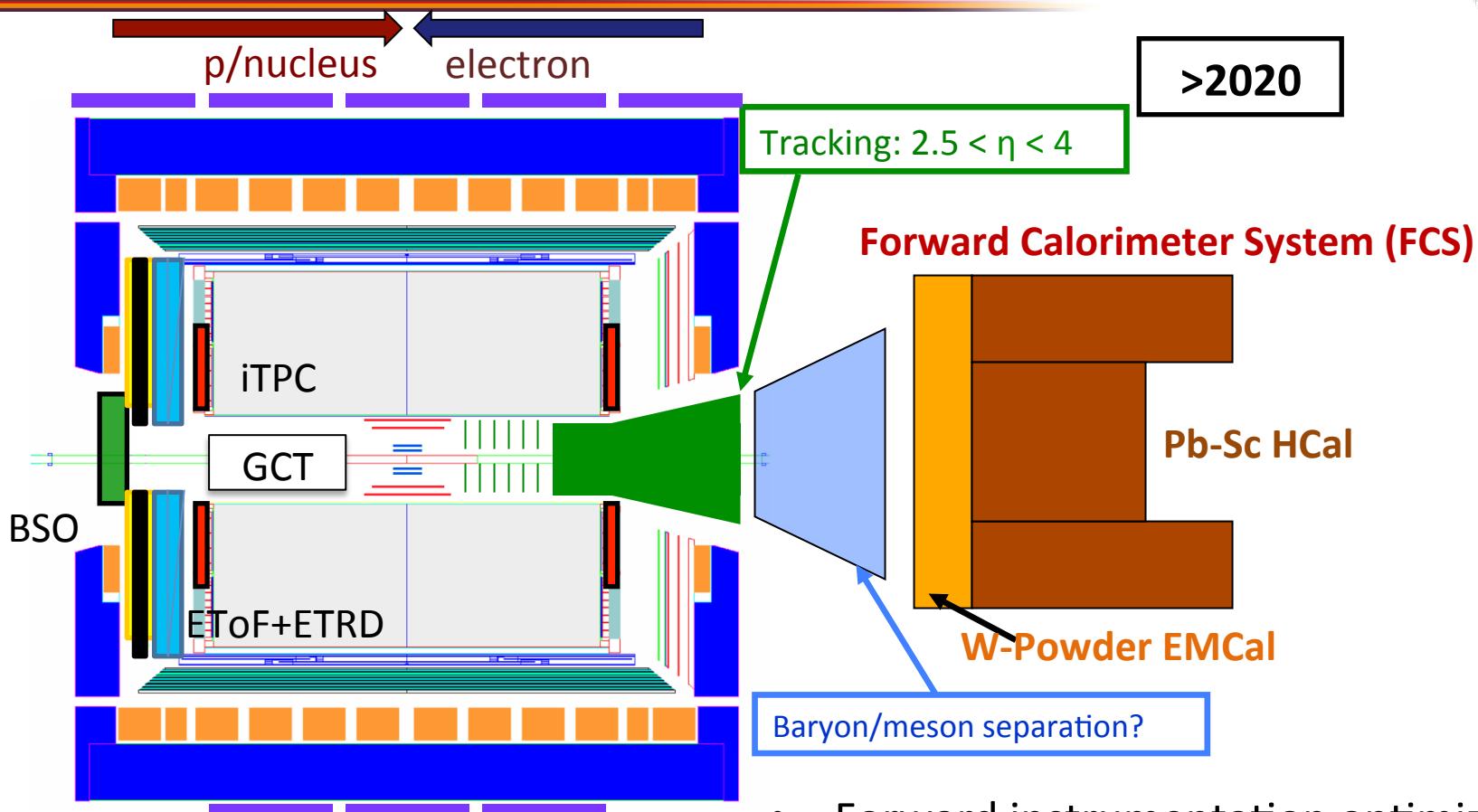
Future Upgrades – Physics Deliverables (EIC white paper)



1. Proton Spin
2. Motion of partons
3. Imaging
4. Dense Gluonic QCD matter
5. Quark Hadronization

Map the physics cases from EIC whitepaper to eSTAR!

Future Upgrades – Forward Instrumentation Upgrade



eSTAR specific upgrades:

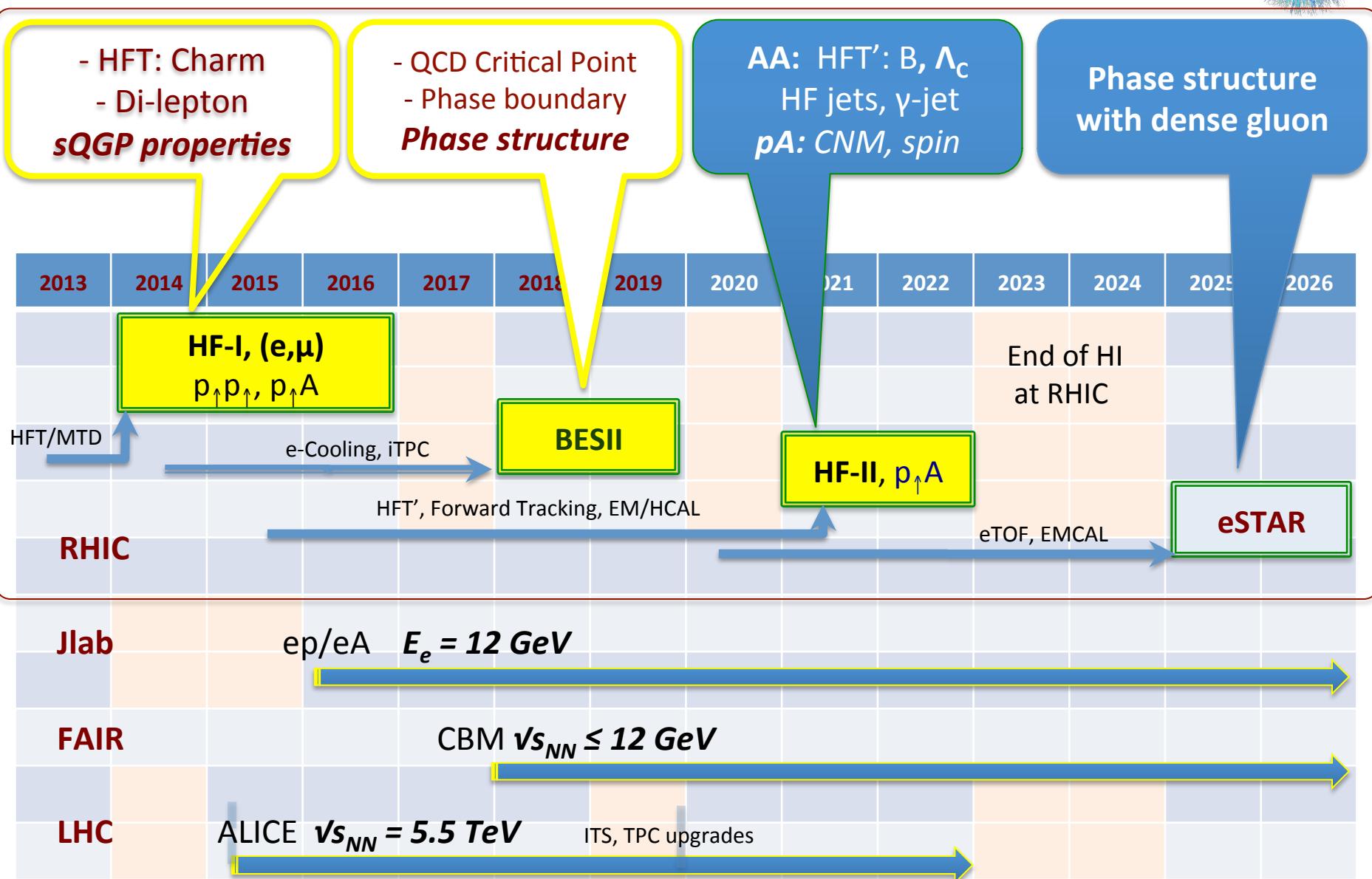
- **GCT**: low mass tracking
- **EToF**: e, π, K identification
- **ETRD**: electron ID and hadron tracking
- **BSO**: 5 GeV, 10 GeV electron beams

- Forward instrumentation optimized for **p+A** and **transverse spin** physics
 - Charged-particle tracking
 - e/h and γ/π^0 discrimination
 - Possibly baryon/meson separation

Summary

- 1) STAR at RHIC: Dedicated facility/Detector for studying matter with QCD degrees of freedom:
 - Properties of QGP
 - Sea quark and gluon contributions to nucleon spin
- 2) Recent: HFT, MTD (finished in 2014)
 - Heavy flavor production, collectivity and energy loss
 - Resonance-Medium interaction, Chiral symmetry restoration
- 3) Middle term: BES-II, forward upgrades (~2016)
 - QCD critical point, phase boundary, transition to eSTAR
- 4) Longer term: eSTAR (~2020)
 - Partonic structures of nucleon and nuclei
 - Dynamical evolution from cold nuclear matter to hot QGP

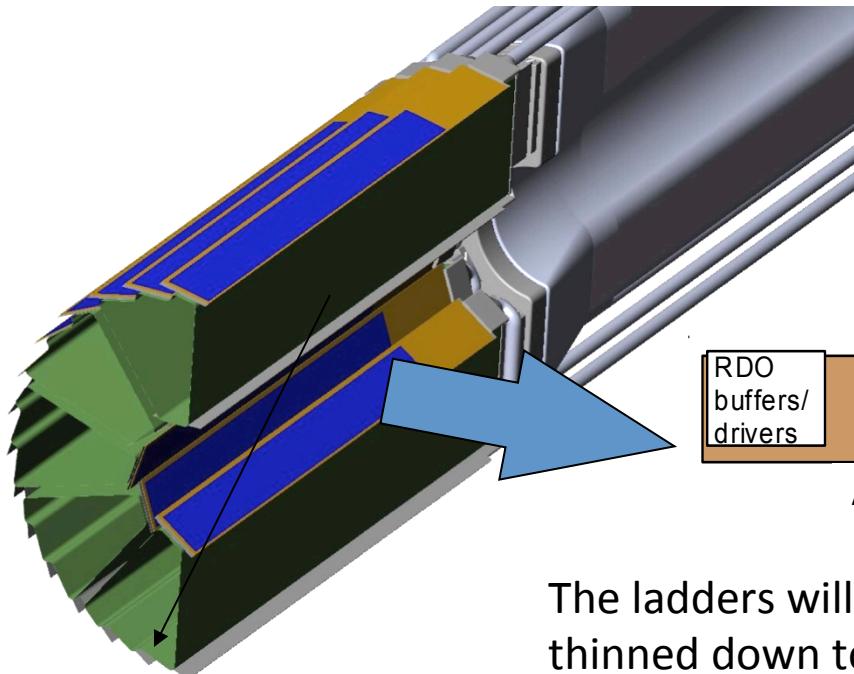
Summary – STAR's Future is Bright!



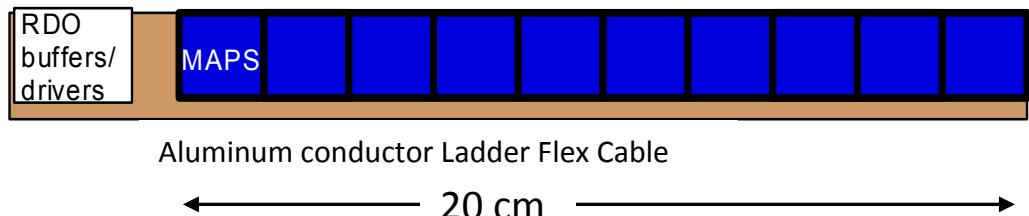
Backup

STAR Recent Upgrades – PIXEL

Carbon fiber sector tubes ($\sim 200\mu\text{m}$ thick)



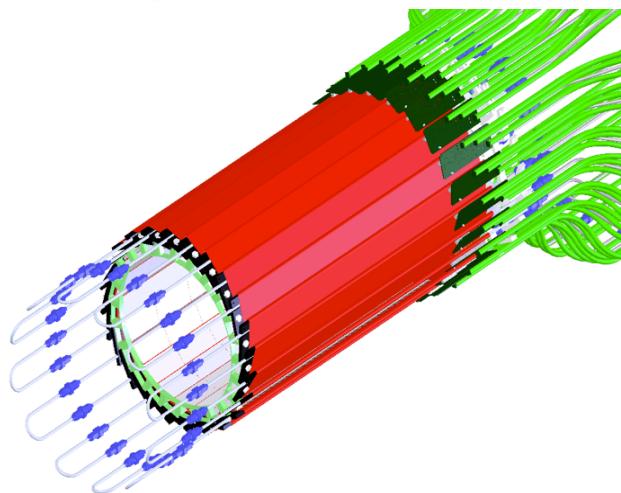
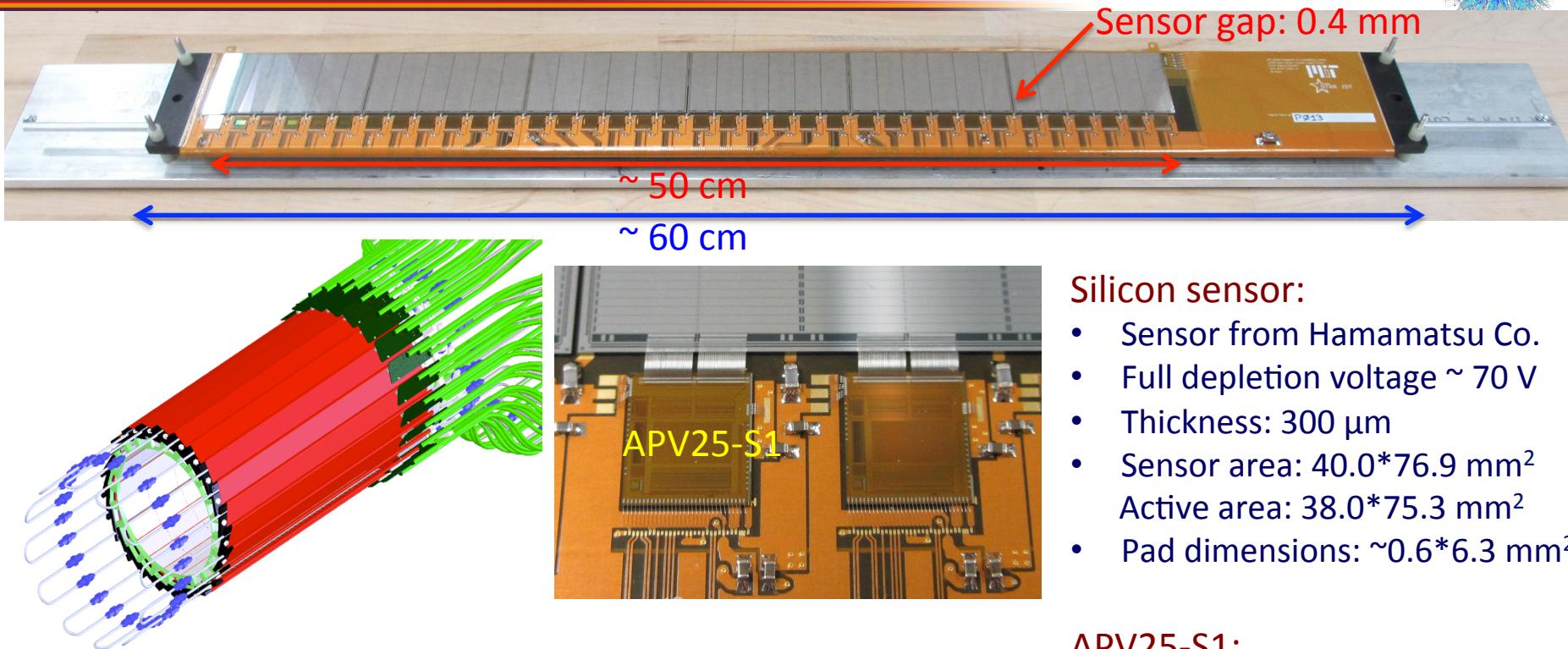
Ladder with 10 MAPS sensors ($\sim 2\times2\text{ cm}$ each)



The ladders will be instrumented with sensors thinned down to 50 micron Si.

Novel rapid insertion mechanism allows effective exchanges and repairs ($\sim 12\text{ h}$)
Precision kinematic mount guarantees reproducibility to < 20 microns

STAR Recent Upgrades – IST



IST consist of 24 staves

IST staves = Carbon fiber ladder + Liquid cooling tube
 + Kapton flex hybrid + Passive components
 + 6 silicon pad sensors +
 + 3 x 12 APV25-S1 readout chips

Electrically divided in 3 units to reduce chance of failure of a full stave

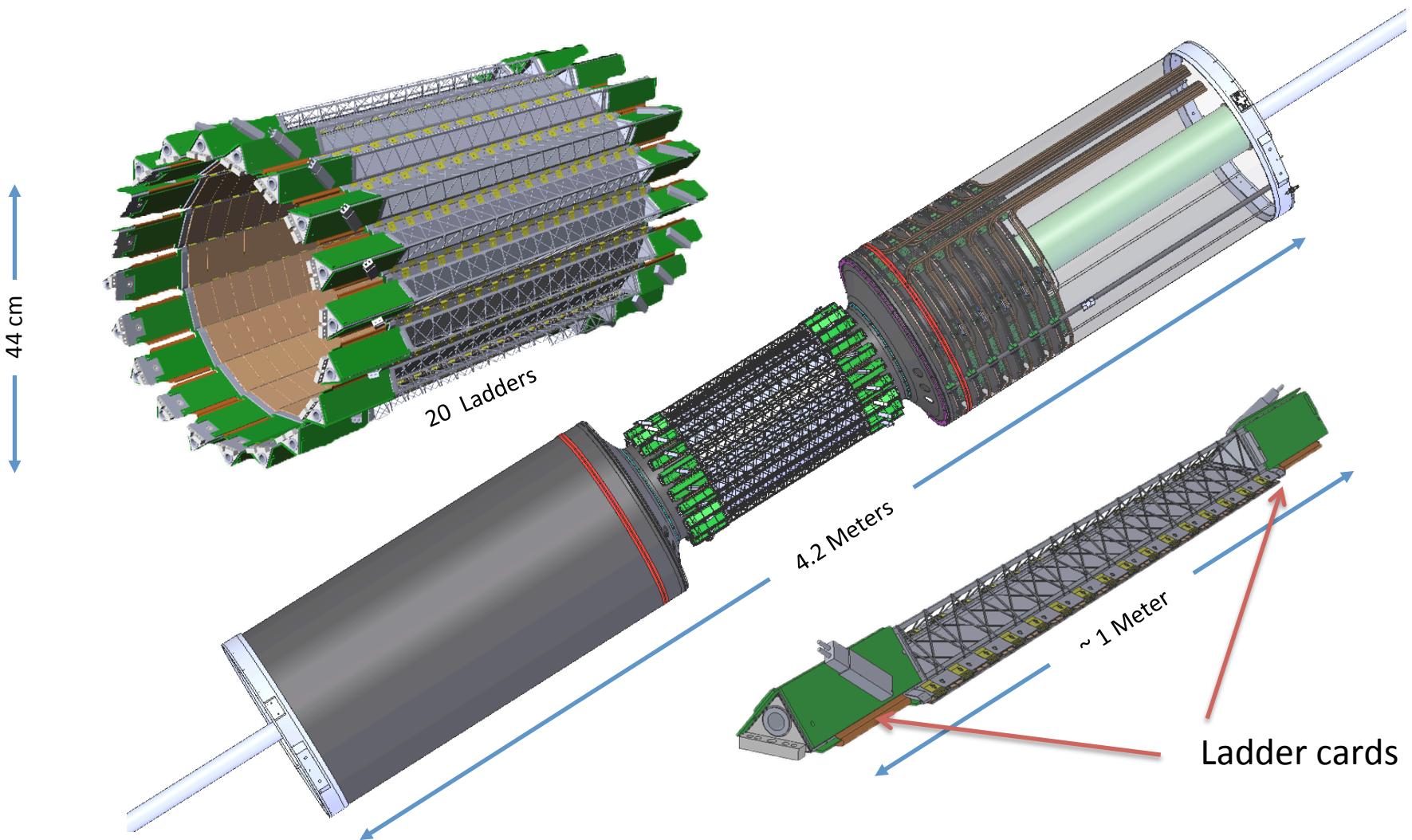
Silicon sensor:

- Sensor from Hamamatsu Co.
- Full depletion voltage ~ 70 V
- Thickness: 300 μ m
- Sensor area: 40.0×76.9 mm 2
- Active area: 38.0×75.3 mm 2
- Pad dimensions: $\sim 0.6 \times 6.3$ mm 2

APV25-S1:

- 0.25 μ m CMOS, radiation hard
- 128 channels parallel sampling
- 40 MHz sampling rate
- 4 μ s analogue pipeline
- $> 15:1$ signal to noise ratio

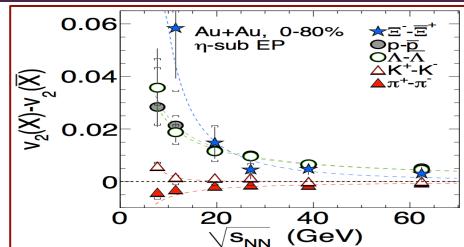
STAR Recent Upgrades – SSD



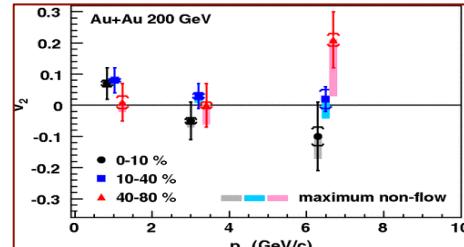
Introduction -- The STAR Experiment



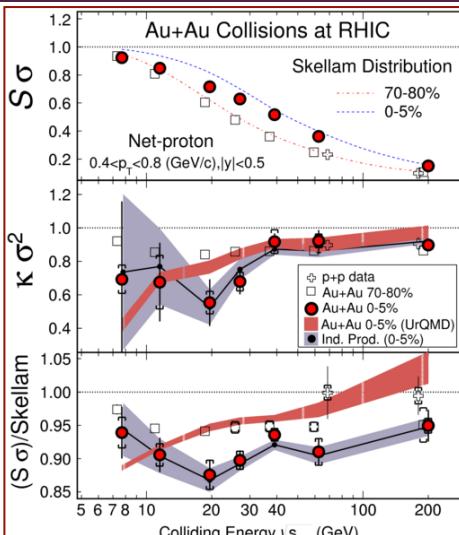
Introduction – STAR Latest Results



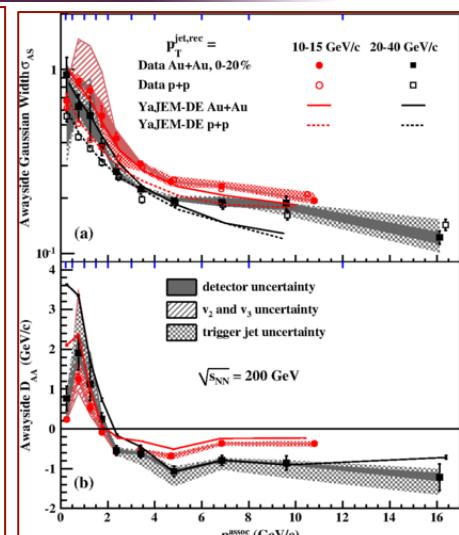
PRL 110 (2013) 142301



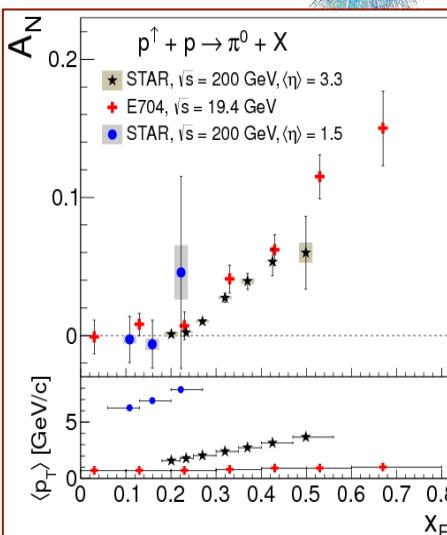
PRL 111 (2013) 052301



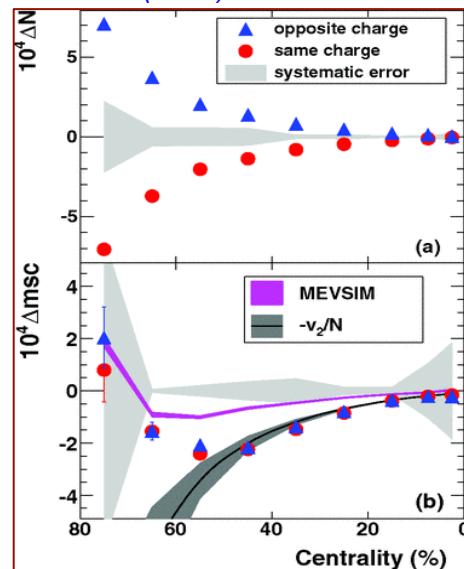
PRL 112 (2014) 032302



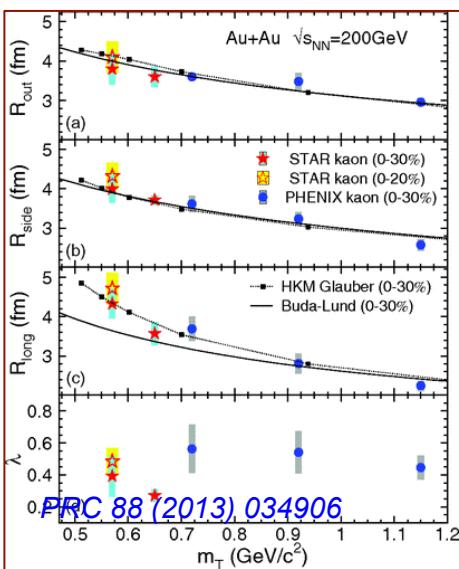
PRL 112 (2014) 122301



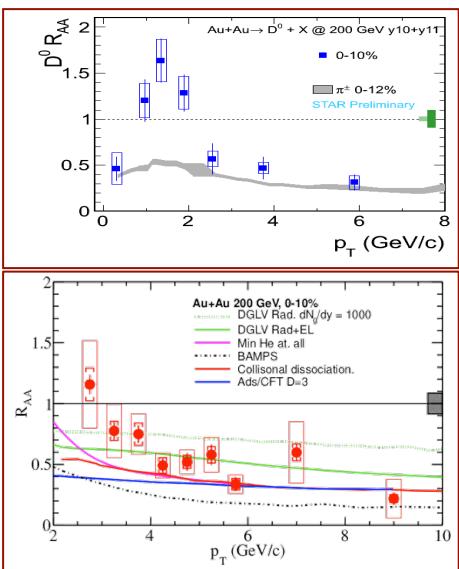
PRD 89 (2014) 012001



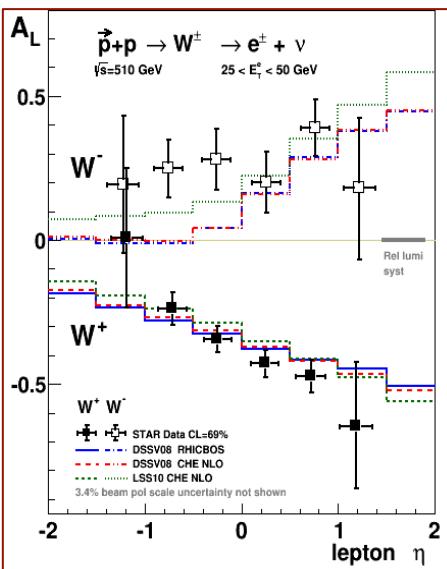
PRC 88 (2013) 064911



PRC 88 (2013) 034906



STAR Preliminary results



STAR Preliminary results